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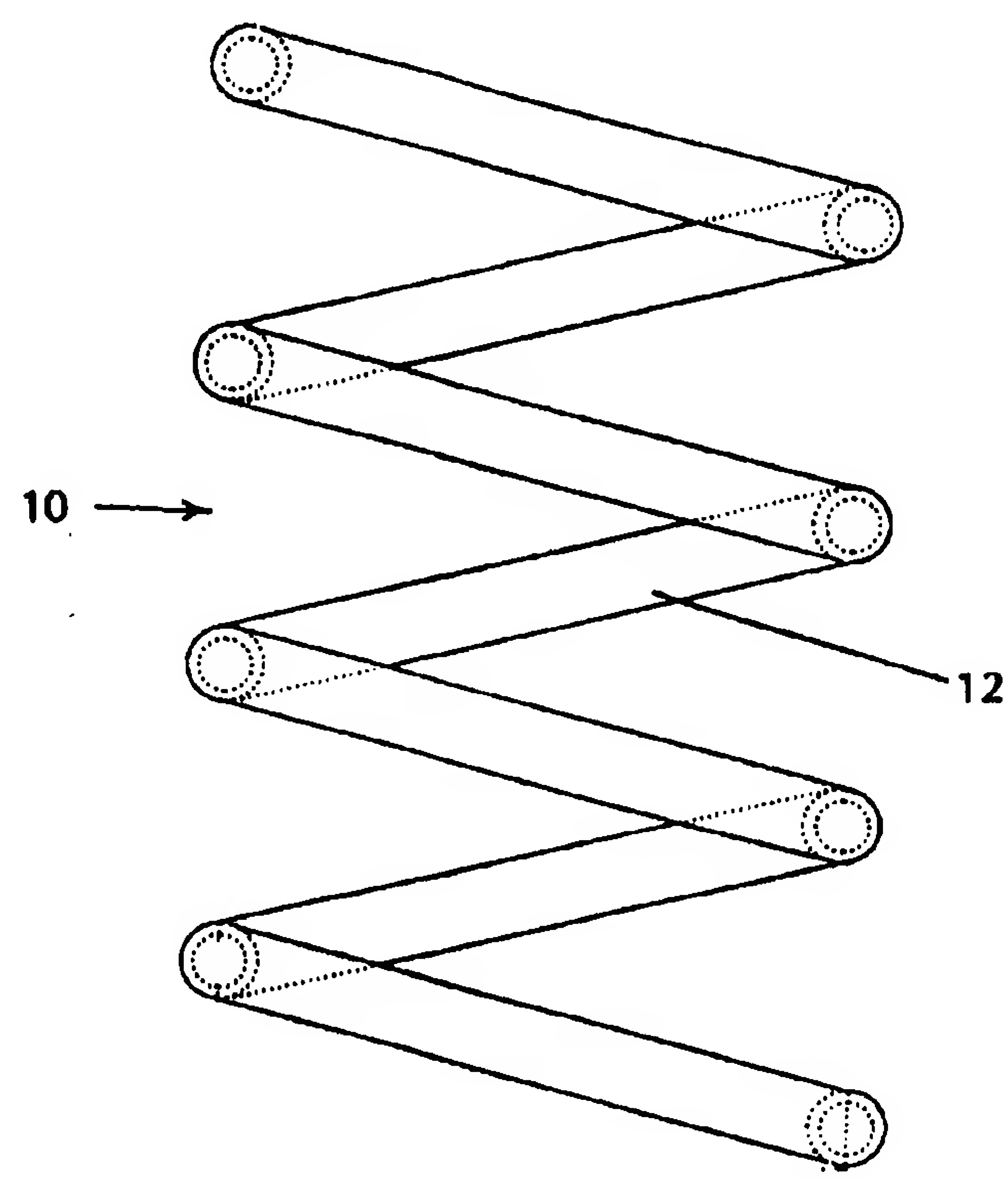
(54) Title: PIEZOELECTRIC ELEMENTS AND DEVICES INCORPORATING SAME

(57) Abstract

A piezoelectric element comprises a helical coil (10) having the piezoelectric properties. The coil (10) may have the properties of a spring and may be formed of a coiled tube. Electrodes may be formed on the inner and outer walls of the tube or within the wall of the tube. The use of the piezoelectric element in an actuator and in an underwater acoustic or seismic sensor is disclosed.



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PIEZOELECTRIC ELEMENTS AND DEVICES INCORPORATING SAME

This invention relates to piezoelectric elements and devices including same for various application, for example for sensing of underwater acoustic signals or seismic signals, and for actuators.

According to a first aspect of the present invention, there is provided a piezoelectric element comprising a coil having piezoelectric properties.

The coil is preferably a helical, helicoidal or planar (eg spiral) coil.

Most preferably, the coil is formed of a coiled tube whose wall has piezoelectric properties.

The coil may have the properties of a spring.

According to a second aspect of the present invention, there is provided a method of producing a piezoelectric element, comprising the steps of forming a filament from a material possessing piezoelectric properties, and coiling said filament to form a coil having piezoelectric properties.

The material having piezoelectric properties may be an extrudable paste composition comprising piezoelectric particles and an organic binder, eg a resin binder. Such composition is preferably dried and sintered after the coiling step.

According to a third aspect of the present invention, there is provided a piezoelectric transducer comprising a piezoelectric element according to

said first aspect of the present invention, and electrodes connected to the piezoelectric element.

In the case where the coil is formed of a coiled tube whose wall has piezoelectric properties, the electrodes may be provided (a) on the inner and outer surfaces of the wall so as to extend longitudinally of the tube, or (b) within the wall of the tube.

In the case where the electrodes are provided on the inner and outer surfaces of the tube walls, it is preferred for each of such electrodes to be provided as a coating or layer on a respective one of said surfaces. Each such coating or layer may be provided after the tube has been formed, eg by a dipping, painting or spraying operation. For example, the layers may be formed after sintering of the tube, using a resin, eg an epoxy resin, loaded with conductive particles, eg of silver, nickel or gold. Alternatively, the electrodes may be formed of platinum or palladium and may be applied after coiling and drying but before sintering. As a further alternative, the electrodes may be formed by co-extruding the layers with the tube. In such a case, the electrodes may also be formed of platinum or palladium

In the case where the electrodes are provided in the tube wall, it is preferred for each electrode to extend helically within the wall of the tube around the longitudinal axis of the latter. In such an arrangement, it is preferred for the helix of each electrode to lie at an angle of about 45° to the longitudinal axis of the tube.

The device may include more than one of said piezoelectric elements. The coil or coils is/are preferably supported of a mandrel or mandrels. Such mandrel or mandrels may be flexible.

According to a fourth aspect of the present invention, there is provided an acoustic or seismic signal sensor, particularly an underwater acoustic signal sensor or a seismic signal sensor, comprising at least one piezoelectric device according to said third aspect of the present invention.

In a particularly preferred embodiment of the sensor, the coil is immersed in a flexible hose filled with an acoustic coupling medium, eg a liquid medium, such as oil. In the case where a number of coils are employed in the length of hose, the coils may be electrically connected either separately, or in parallel, or in series to a voltage detector.

According to a fifth aspect of the present invention, there is provided an actuator comprising a piezoelectric device according to said second aspect of the present invention, wherein means are provided for applying a voltage to said at least one coil, and wherein the electrodes are connected with the coil and are disposed such that application of a voltage across the electrodes causes at least one dimension of the coil to vary.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:-
Fig 1 is a side view of a piezoelectric element according to said first aspect of the present invention,

Fig 2 is a cross section through part of one embodiment of a piezoelectric device according to said third aspect of the present invention incorporating the piezoelectric element of Fig 1,
Fig 3 is a side view showing part of a piezoelectric tube forming part of another embodiment of piezoelectric device according to said third aspect of the present invention,
Fig 4 is a cross-sectional view of the tube of Fig 3,
Fig 5 is a view showing how electrodes in the tube of Figs 3 and 4 are connected,
Fig 6 is a schematic axial section through an underwater acoustic signal sensor according to said fourth aspect of the present invention, and
Fig 7 is a schematic sectional view of an actuator according to said fifth aspect of the present invention.

Referring now to Fig 1 of the drawings, the piezoelectric element illustrated therein comprises a coil 10 having piezoelectric properties. The coil is defined by a tube 12 which has been helically coiled.

The coil 10 is produced by extruding a dough of piezoelectric ceramic powder, polymer and liquid vehicle through an annular die in a manner which is known per se in viscous polymer processing (VPP). Following extrusion of the tube 12, it is wound onto a cylindrical mandrel (not shown) whilst still plastic, to form the coil 10, and then sintered. The resultant structure, after poling if necessary, is a coil having piezoelectric properties.

Referring now to Fig 2, the tube 12 after sintering has inner and outer electrode layers 14 and 16 applied to the inner and outer surfaces of the wall of the tube 12. The inner and outer electrodes 14 and 16 may be

applied simply by dipping the tube 12 after sintering in a liquid polymer composition containing suspended electrically conducted particles, eg, silver, nickel or gold so that the inside and outside surfaces of the tube 12 are coated, followed by curing.

Example

100 g of PZT-5A powder (supplied by Morgan Matroc Ltd, Vernitron Division, Thornhill, Southampton, UK; average particle size, 1 μm), 5 g of polyvinyl alcohol powder (Gohsenol KH17s supplied by Nippon Gohsei, Osaka, Japan), 2 g of methylcellulose powder ("Tylose", supplied by BDH Merck Ltd, Leicestershire, UK) and 8 g of water were mixed together on a twin roll mill for 10 minutes to produce a uniform 1 mm thick sheet. The sheet was rolled into a solid cylinder which was then extruded through an annular tube die having, in this embodiment, a 3 mm outside diameter and a 2 mm inside diameter. As the tube was being extruded, it was wound onto a cylindrical mandrel having a diameter of 42 mm to form a coil. The coil was then dried at room temperature for 24 hours, removed from the mandrel and placed onto a refractory alumina cylinder having an outer diameter of 34 mm. The coil on the cylinder was then sintered horizontally by heating it at a rate of 1 °C per min to 600 °C, then at a rate of 20 °C per minute to 1200 °C, holding it at 1200 °C for five minutes and then cooling it at 20 °C per minute to room temperature.

Following sintering, the coil 10 was removed from the refractory alumina cylinder and the electrodes 14 and 16 were formed by applying to the inner and outer surfaces of the wall of the tube 12 a mixture of a silver-loaded epoxy resin (Eccobond 56C, supplied by W.R. Grace Ltd, London, UK) with 10 % by weight of toluene (BDH Merck Ltd), followed

by curing at 90 °C for 30 minutes. Then, separate electrical connections were made to the inner and outer electrodes 14 and 16 using silver wire bonded using the same silver-loaded epoxy resin which was used to form the electrodes 14 and 16.

The resultant piezoelectric device was then poled by immersing the coil 10 with electrodes 14 and 16 thereon into an oil bath at 120 - 130 °C and applying a voltage across the wall thickness of the tube 12 of 1.25 kV for 10 minutes. Following this, the resultant piezoelectric device was removed from the oil bath and cleaned thoroughly.

Referring now to Figs 3 and 4, the piezoelectric device illustrated therein comprises coil 10 formed of piezoelectric tube 12 which, in this embodiment, has three electrodes 14 alternating with three electrodes 16 disposed within the wall of the tube. As can be seen from Figs. 3, 4 and 5, the electrodes 14 and 16 are equi-spaced apart around the axis of the tube 12 and also extend helically with respect to the longitudinal axis of the tube 12. In this embodiment, each helix is disposed at 45° relative to the longitudinal axis of the tube 12, as shown in Fig 3.

As shown in Fig 5, all of the electrodes 16 are connected to ground, whilst all of the electrodes 14 are connected to a higher voltage potential line.

In the above-described embodiments, the tube is of circular cross-section. However, it is within the scope of the present invention for the tube to be of any desired cross-sectional shape, eg square, triangular or octagonal. In the above embodiments, the tube is of constant cross-sectional shape. However, it is also within the scope of the present

invention for the tube to be tapered. Furthermore, it is possible for the coil itself to be tapered or other form rather than of constant cross-sectional area along its length. Instead of being of circular cross-sectional shape, it is also possible for the coil to have another cross-sectional shape, eg square or other rectangular shape.

The device of Figs 3 and 4 may be produced by disposing strips which are to form the electrodes 14 and 16 into slots in a rotary annular die and extruding the tube 12 in a manner similar to that described above in relation to the embodiment of Fig 1 whilst rotating the die thereby to form the tube 12 and, at the same time, impart a helical twist to the metal strips forming the electrodes 14 and 16.

The poling direction of the sections of the piezoelectric material forming the tube 12 is shown by the arrows in Fig 5.

Referring now to Fig 6 of the drawings, there is illustrated an underwater acoustic signal sensor which is formed of a plurality of piezoelectric devices of the general type described hereinabove in relation to Fig 2 which are disposed in end-to-end relationship on a flexible central cylindrical core 18. This assembly is disposed in a flexible hose 20, and electrical connections to the electrodes 14 and 16 are by way of electrical leads 22 extending along the hose 20 to a ship used to tow the hose 20 through the water. The hose 20 is filled with oil so that the coils 10 are acoustically coupled with the surrounding water. It will be understood from the description in relation to Figs 1 and 2 that the poling direction of the piezoelectric material forming the tube 12 is in the radial direction relative to the longitudinal axis of the tube 12. Acoustic signals in the surrounding water are transmitted through the

hose 20 and via the oil to the coils 10. The resultant deflection of the coils 10 causes a corresponding voltage signal to be passed along the electrical connections 22 to a ship-mounted voltage sensing apparatus so that the acoustic signals can be detected electrically and analysed. The use of a coil or coils is considered to be particularly advantageous in that a very large surface area of piezoelectric material is available to enable high sensitivity to be achieved. Also, the large capacitance allows electrical matching to the sensing apparatus.

Referring now to the embodiment of Fig 7, there is illustrated an actuator comprising one or more piezoelectric coils 10 of the type described above in relation to Figs 3 to 5 mounted on a central core 23 extending laterally from a support 24 to which one end of the coil 10 is secured. The other end of the coil 10 abuts against a moveable output element 26 slidable on the core 23.

The electrodes (which are not shown in Fig 7 but which correspond to the electrodes 14 and 16 of Fig 5) are connected to a variable voltage supply 28. It will therefore be appreciated that variation of the voltage supplied by the voltage supply 28 enables the effective length of the coil 10, and thereby the displacement of the output member 26 relative to the core 22, to be altered. Relatively large amounts of displacement can be achieved as compared with the case of a solid bar of piezoelectric material.

In a modification of the arrangement of Fig. 7, the coil 10 and electrodes 14 and 16 are of the type described with reference to Figs. 1 and 2. The coil 10 is supported with its axis vertically disposed by means of a spike which extends from the support 24 and which is driven into the ground.

The member 26 is arranged to act as a mass damper. With voltage sensing equipment connected instead of voltage supply 28, the arrangement thus provided can be used as a sensitive geophone for the sensing of seismic signals. Alternatively, the coil 10 may be supported with its axis disposed other than vertically, e.g. horizontally. In further modifications, the coil 10 and electrodes 14 and 16 of the type described with reference either to Fig. 2 or to Figs. 3 to 5 may be incorporated in a displacement sensor, a velocity sensor or an acceleration sensor wherein displacement, velocity and acceleration forces, respectively, which are applied to member 26 can be sensed by appropriately monitoring the output signals from the electrodes 14 and 16.

CLAIMS

1. A piezoelectric element comprising a coil (10) having piezoelectric properties.

2. An element as claimed in claim 1, wherein the coil (10) is a helical, helicoidal or planar coil.

3. An element as claimed in claim 1 or 2, wherein the coil (10) is formed of a coiled tube (12) whose wall has piezoelectric properties.

4. An element as claimed in any preceding claim, wherein the coil (10) has the properties of a spring.

5. A method of producing a piezoelectric element, comprising the steps of forming a filament from a material possessing piezoelectric properties, and coiling said filament to form a coil (10) having piezoelectric properties.

6. A method as claimed in claim 5, wherein the material having piezoelectric properties is an extrudable paste composition comprising piezoelectric particles and an organic binder.

7. A method as claimed in claim 6, wherein the composition is dried and sintered after the coiling step.

8. A piezoelectric transducer comprising a piezoelectric element as claimed in any one of claims 1 to 4, and electrodes (14, 16) connected to the piezoelectric element.

9. A piezoelectric transducer as claimed in claim 8 when appended to claim 3, wherein the electrodes (14,16) are provided on the inner and outer surfaces of the wall so as to extend longitudinally of the tube.

10. A piezoelectric transducer as claimed in claim 8 when appended to claim 3, wherein the electrodes (14,16) are provided within the wall of the tube.

11. A piezoelectric transducer as claimed in claim 9, wherein each electrode (14,16) is provided as a coating or layer on a respective one of said surfaces.

12. A piezoelectric transducer as claimed in claim 10, wherein each electrode (14,16) extends helically within the wall of the tube around the longitudinal axis of the latter.

13. A piezoelectric transducer as claimed in claim 12, wherein the helix of each electrode (14,16) lies at an angle of about 45° to the longitudinal axis of the tube.

14. An acoustic or seismic signal sensor comprising at least one piezoelectric device as claimed in any one of claims 8 to 13.

15. A sensor as claimed in claim 14, wherein the coil is immersed in a flexible hose (20) filled with an acoustic coupling medium.

16. An actuator comprising at least one piezoelectric device as claimed in any one of claims 8 to 13, wherein means (28) are provided for applying a voltage to said at least one coil (10), and wherein the electrodes (14,16) are connected with the coil (10) and are disposed such that application of a voltage across the electrodes causes at least one dimension of the coil (10) to vary.

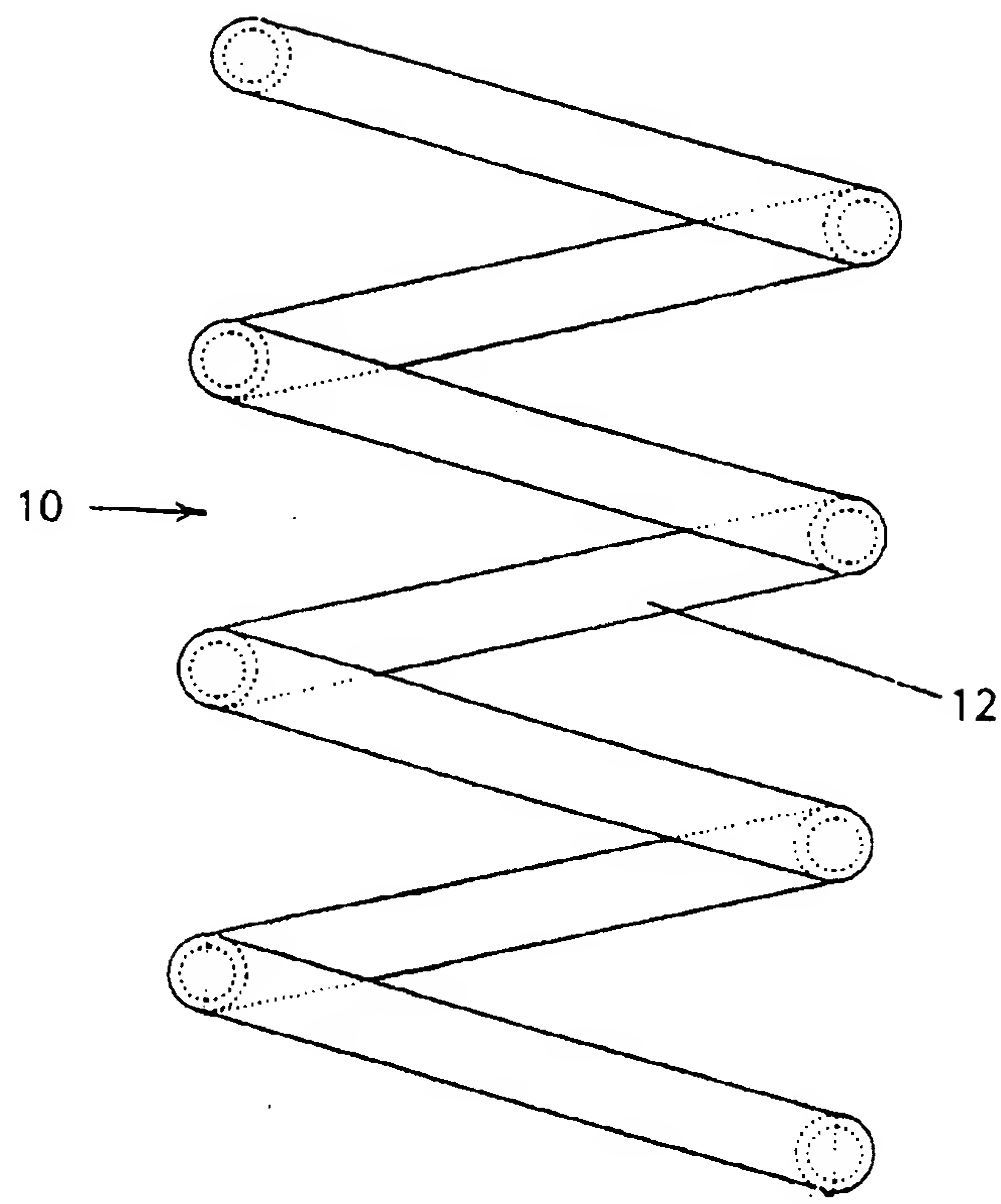
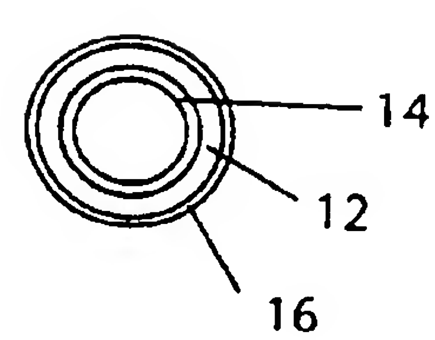


Fig. 1

Fig. 2



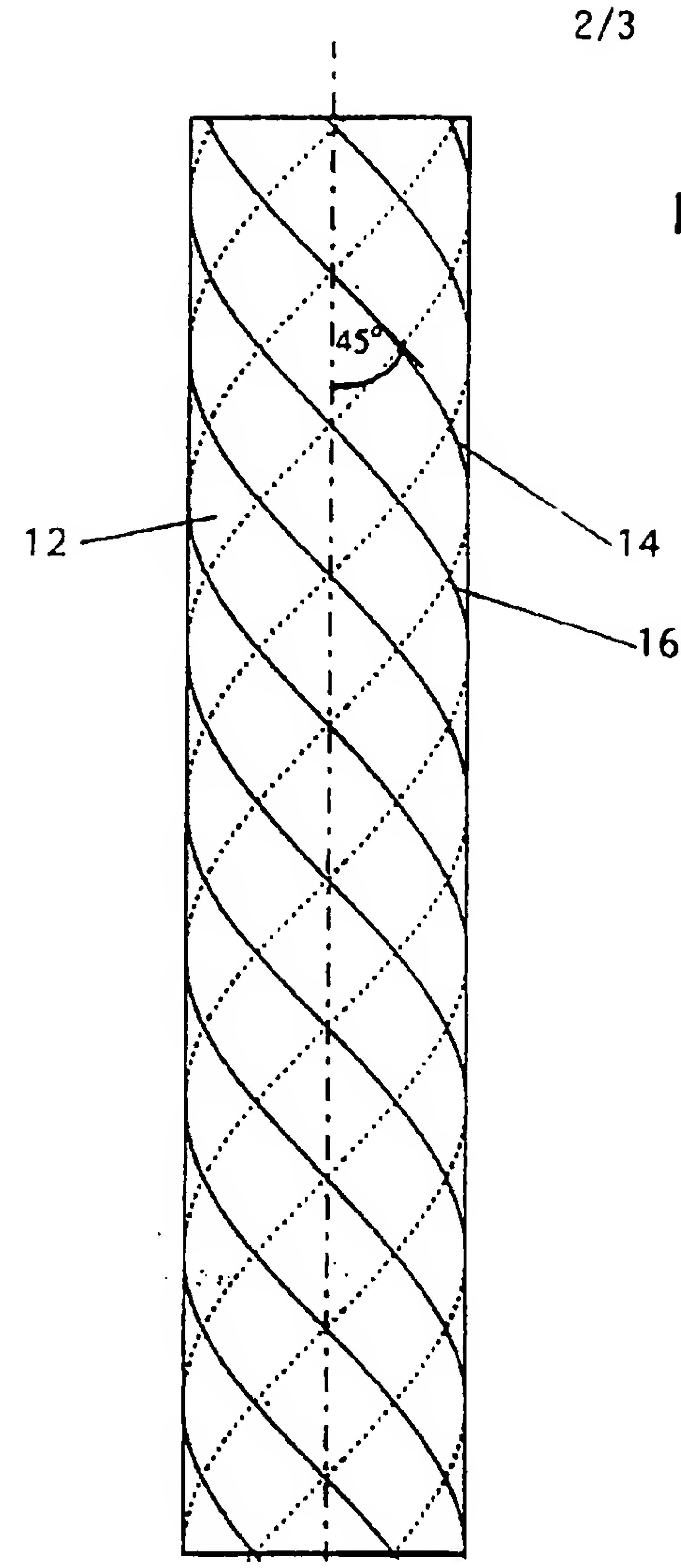


Fig. 3

Fig. 4

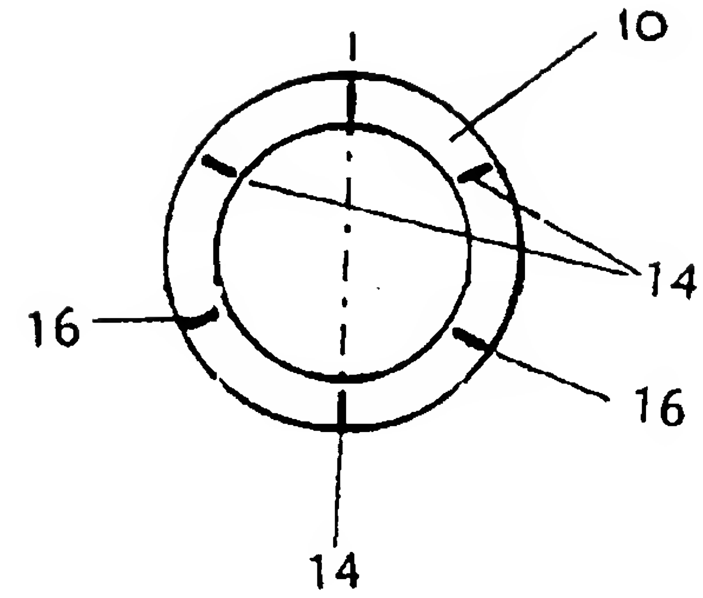
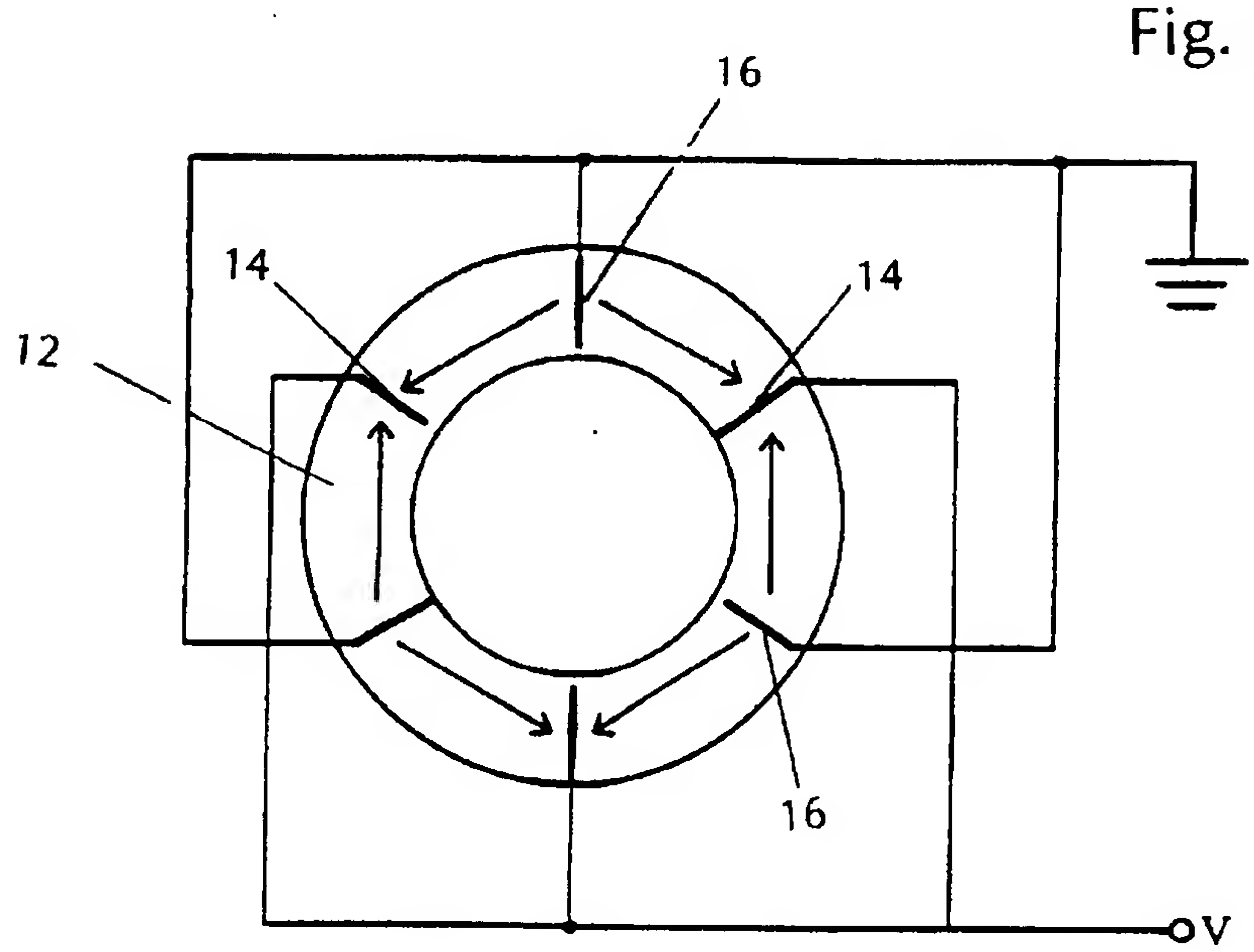


Fig. 5



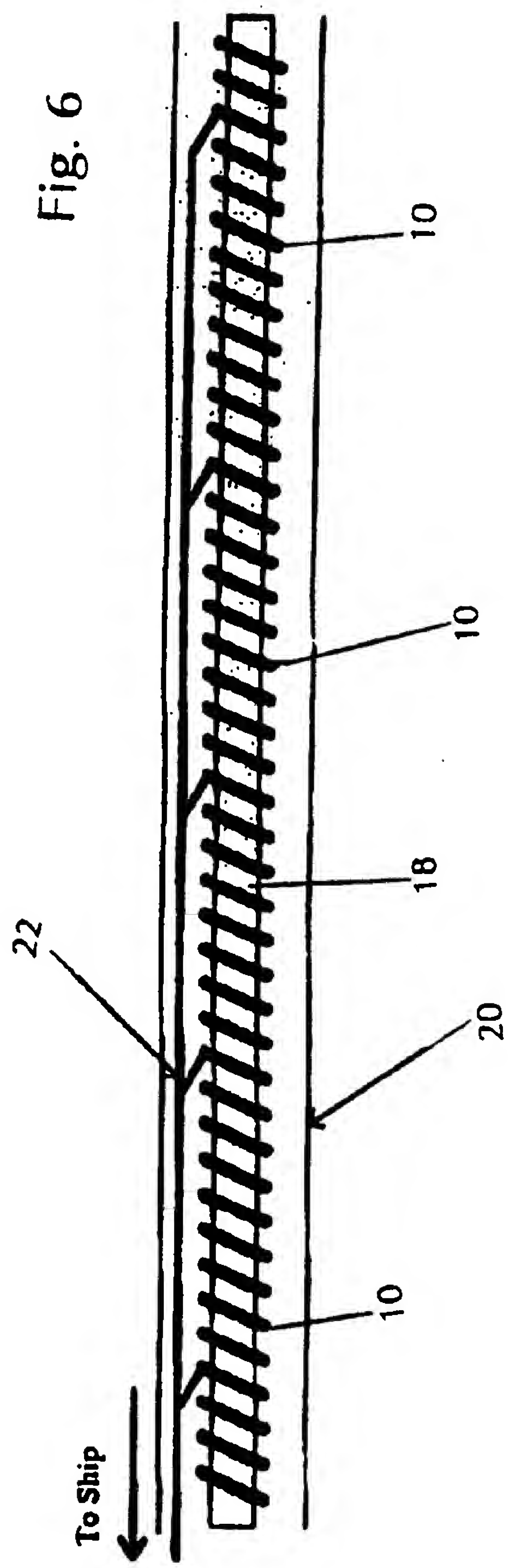


Fig. 6

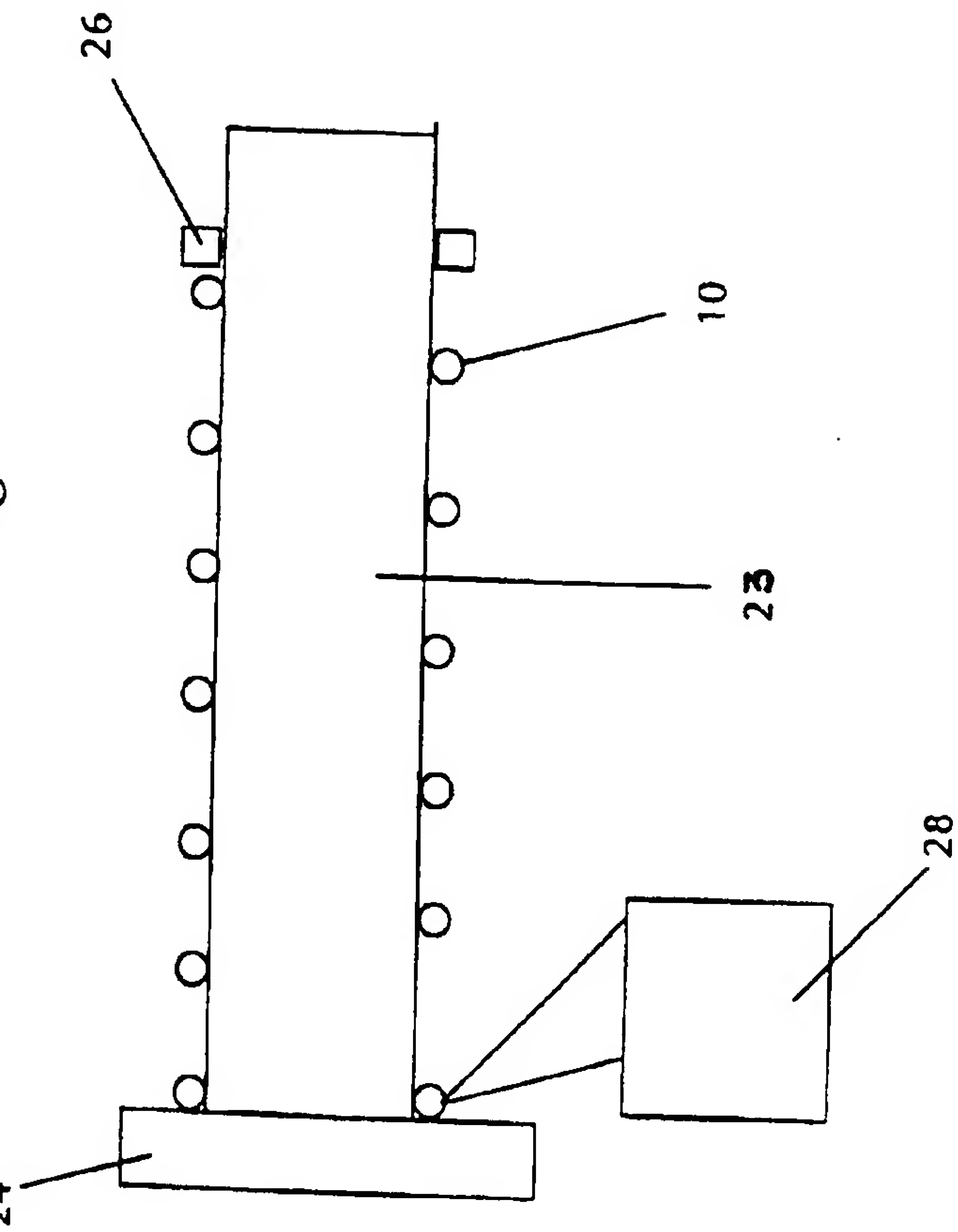


Fig. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/02301

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01L41/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 119 482 A (KI) 4 August 1972 see claim 1	1
X	US 3 900 748 A (ADLER ROBERT) 19 August 1975 see abstract; figure 1	1
X	US 4 690 143 A (SCHROEPPEL EDWARD A) 1 September 1987 see abstract; figure 2	1
X	EP 0 021 879 A (THOMSON CSF) 7 January 1981 see abstract; figure 4	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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2 December 1997	09/12/1997

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Information on patent family members

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